

THE CARDIAC CYCLE AS A PHYSIOLOGICAL
DETERMINANT OF ENERGY DISTRIBUTIONS
IN SPEECH

MARTIN F. PALMER

Municipal University of Wichita

Reprinted from SPEECH MONOGRAPHS, December, 1937

Ann Arbor
1938

1937



THE CARDIAC CYCLE AS A PHYSIOLOGICAL DETERMINANT OF ENERGY DISTRIBUTIONS IN SPEECH*

MARTIN F. PALMER
Municipal University of Wichita

THIS investigation is an outgrowth from a suggestion made by Professor J. H. Muyskens of the University of Michigan in 1931¹ that a speech curve is very similar to the Traube-Hering wave in circulation. "Far be it from me to suggest a coincidence, but I have felt for some time that speech must be correlated with these vegetative functions." The investigation concerns itself with energy distributions in speech, and the effect of one of these vegetative functions, that of the circulatory rhythms, upon the energy distributions.

Prior to the experimentation reported by Professor Muyskens in "The Hypha"² little objective work had been done on accent. Since that time incidental work has been done by Shohara,³ Steer and Tiffin,⁴ E. Ray Skinner,⁵ and others, but with the exception of Shohara, these investigations are open to criticism from the objective point of view. Shohara realized the necessity for a correlation between the vegetative rhythms and accent—*i.e.*, large energy distributions. "The problem of accent must also be considered in relationship to the alimentary acts . . . an even rhythmicity, that is,

* A condensation of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Science in the University of Michigan under the following graduate committee: Professors C. L. Meader, J. H. Muyskens, H. H. Shohara, Leon H. Strong, N. E. Nelson.

¹ Muyskens, J. H., "The Smallest Aggregate of Speech Movement Analyzed and Defined. The Hypha," Doct. Diss. Univ. of Mich., Part I, Accent; pub. *Vox*, 17 Jahrgang, Heft 2, Mai, 1931.

² *Ibid.*

³ Shohara, Hide, "A Contribution to the Genesis of the Articulatory Movements of Speech, with Special Reference to the Processes of Chewing, Sucking, and Swallowing," Doct. Diss. Univ. of Mich., abstract pub., *Quarterly Journal of Speech*, 21, June, 1935.

⁴ Steer, Max D., and Tiffin, Joseph, "A Photographic Analysis of the Use of Intensity by Superior Speakers," *Studies in Phonetics and Phonology*, 1, September, 1934.

⁵ Skinner, E. Ray, "A Calibrated Recording . . . etc.," *SPEECH MONOGRAPHS*, 2, October, 1935.

evenness of energy output and periodicity in the wave of contraction are characteristic of the peristaltic activity of smooth muscle . . . also characteristic of the stages of the swallowing process . . . Variation in energy does occur here as a result of the resistance to progress offered by the condition of the bolus. Thus accent in language has its archetype in swallowing."

Reasoning from the physiological processes of anabolism and katabolism, Shohara⁶ in 1934 reached the conclusion that "this alternation in the extent of energy output is a fundamental characteristic of all life processes, including speech, and is a physiological basis of rhythm. In the English language, these strong energy outputs, marked by loudly pronounced accents, succeed one another at a rate of about one per minute."⁷

Early in the investigation, before objective work was commenced, the investigator was struck independently by the same conclusion. It seemed that these loudly pronounced accents occurred regularly near the ventricular systole of the radial pulse. Listening to various speakers seemed to confirm this suspicion. It should be made clear that these stresses, or accents, or large energy quanta in speech are not necessarily the result of the so-called pronunciation stress, but occur as a result of fundamental meaning content. These large energy quanta may fall on conventionally accented hyphae, or they may not. The strictly conventional pronunciation stress is limited in its appearance to other bio-linguistic laws with which this investigation is not concerned.

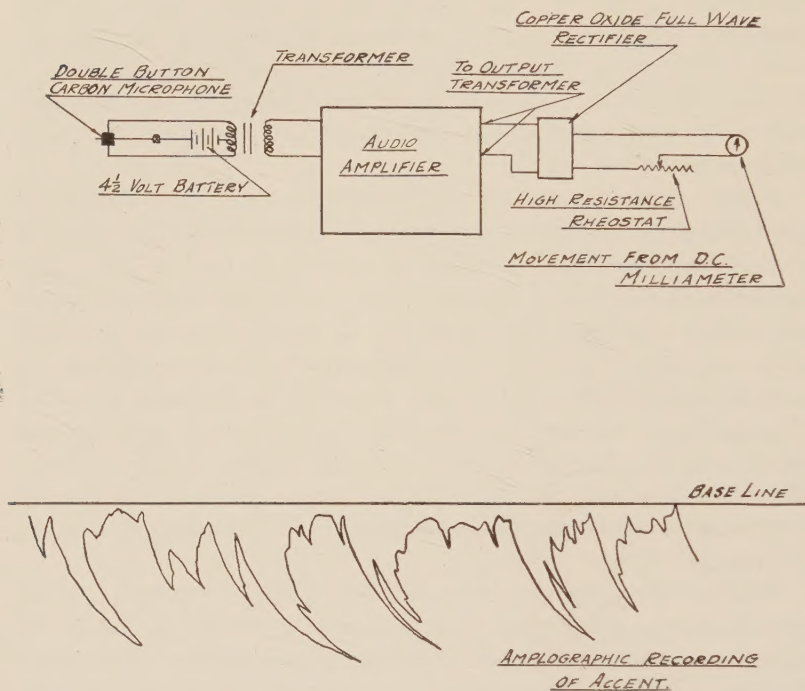
Whether there are physiological determinants or regulators of this play of energy distribution upon the specific details of the speech continuity forms the essential cause for the appearance of this investigation. Due to the large amount of muscle, nerve, and glandular tissue involved, any determination of the place of this energy distribution in the scale of functions must lead inevitably to a closer understanding of cellular organization and integration.

⁶ Shohara, Hide, "Some Biological Factors Involved in Coptic Sound Changes. App. to Coptic Sound Change," Worrell, W. H., Univ. of Mich. Humanistic Series, Vol. XXVI.

⁷ The actual rhythm of these large accents in the data compiled here was 129.78 per minute, which brings the rhythm closer to the United States Army step. The ear must miss then approximately $\frac{1}{3}$ of these accents. The ear may register differing energy complexes in an entirely different manner, or the meaning content may confuse the ear. The problem cannot now be settled.

APPARATUS, SUBJECTS, TYPES OF SPEECH RECORDED

The objective study was commenced with the equipment used by Muyskens for "The Hypha," with the addition of a Gsell sphygmomanometer. Upon analysis of the records, it was seen that too many factors which were uncontrollable had entered the results. Hysteresis and other physical errors of the apparatus, and the dis-



comfort of the subjects rendered any results questionable. Muyskens had already suggested in the Hypha several means of obtaining energetic measurements, but all of them were cumbersome for a large scale undertaking, and none of them were free from inertia and momentum errors. Professor J. M. Schmidt of Hillsboro College suggested that since the frequencies in an electrical hook-up travel along the wire as alternating frequencies a full wave copper oxide rectifier connected to a DC milliammeter would give the result desired.

The amplograph⁸ consists of a two button carbon microphone

⁸ See diagram.

connected to a transformer and an audio-amplifier. From the amplifier the alternating frequencies are led to the rectifier, which changes the alternating current to a direct current fluctuating in amperage as the waves build up and down in amplitude and complexity. This increase and decrease is not gradual, but sudden, since the energy builds up by the square of the frequency complexes times the amplitude.⁹ The rectifier is connected to a milliammeter, the glass face of which was removed, a brass bar added to the back and placed in a right angle clamp attached to a pivoting metal support whose vertical position can also be adjusted by means of a thumb screw and spirit level.¹⁰ A dog's hair was drawn through rubber cement and attached to the stylus of the recorder, and was found very satisfactory, being light and limber, yet stiff enough to record well on the smoked kymograph record. The milliammeter recorder has a hair spring adjustment so that when the recorder is turned on its side to record on the kymograph, the weight of the hair and stylus can be compensated.

Since the stylus does not have to travel back and forth with each double vibration, the usual inertia and momentum errors are mechanically eliminated, and the remainder were largely checked in the analysis by counting the absolute onset of the sudden increase in energy and ignoring the overshoot of the stylus at the bottom of its swing.¹¹

The respiratory rhythms were measured by the Lombard apparatus, and the radial pulse was taken by means of a Lombard radial pulse apparatus, and the radial pulse curve was recorded synchronously with the amplographic curves. The records were timed with an electro-magnetic timer operating at $\frac{1}{5}$ second. Extreme care was used to prevent motor and gear vibration by means of additional felting and loose pulley belts waxed with beeswax. No vibration was observable in the records.

The subjects were all adults of no known cardiac pathology as ascertained in routine physical examinations by the family physician. The age range was 20-40, with a mean of 26. 42 were female, 21

⁹ See diagram of amplograph curve.

¹⁰ Experimental support, Eberbach.

¹¹ In any further experimentation along these lines, the possibility of recording on film with the cathode ray should not be overlooked. A quantitative measurement could be obtained. The cathode ray recorder should be so arranged that the light beam would travel vertically; the film could be gradated as in decibel apparatus, and analysis should be comparatively easy.

male.¹² Seven were stutterers;¹³ 5 were male, 2 female, with a mean age of 21.5.

45 records were made of normals reading aloud selections taken at random from newspapers and magazines. After the records had been fixed, the selection read was pasted to the back of the record. 5 records were of normals responding to questions asked by the operator. 3 records were of normals repeating the nonsense syllable "pa." 3 records were of normals repeating again and again the series: "pa, ko, ta, pe, tar, ki, ne, ba, ra, sa, da." 6 records were of stutterers reading aloud. One record was made of a stutterer responding to questions.¹⁴

The subjects were told an experimental record on speech was being run, and given the material. No further instructions were given, since subjects do not have to be instructed in the use of this type of apparatus.

ANALYSIS OF THE RECORDS; COLLECTION OF DATA

The customary techniques for analysis of kymograph records were followed, making corrections for alinement, distortion, etc.¹⁵ The phasic points measured were the points of onset of large and sudden changes in the amplograph line, and the points of onset of the primary wave of the radial pulse.¹⁶

The percentages of time which elapsed between the onset of the primary wave and the onset of a large change in the amplograph line were calculated, giving the proportion of the pulse beat which had elapsed before the accent occurred. This was necessary since the pulse rates varied between 1.4 and 6.4 fifths seconds, and a common basis of comparison was necessary to establish statistical significance, and determine the cardiac relationships. A separate tabulation was made for each pulse rate. Calculations were carried to the second place. The total number of accents occurring on each pulse rate was divided by the number of percentage integers at that pulse rate. Thus,

¹² No note is taken in this investigation of sex differences.

¹³ Stuttering being a "disorder of verbal rhythm."

¹⁴ The records were of differing lengths, and the content cannot be judged by the number of records.

¹⁵ Lombard, Warren P., *Laboratory Work in Physiology*, 3d ed., George Wahr, 1920, pp. 276-284.

¹⁶ The dicrotic notch was discarded, due to inaccuracy in relationship to the heart.

a pulse rate of 3.0 had a total of 437 accents. The chance dispersal should have located 14.57 accents on each possible percentage point.

Next to avoid the unfair comparisons presented by the multiplication table, this chance dispersal total was collected and totaled for each percentage point. This gave the expectation by chance for the occurrence of large energy quanta from 00 to 98%. Since the computation was carried to the second place only, a cross total was made with an error resulting of .02 on each percentage point. Since this could not affect any result the error was allowed to stand.

SYNTHESIS OF THE DATA, AND GROSS RESULTS

The accumulated material was next examined by the Bernoulli formula. The total accents falling on each percentage point were compared with the chance dispersal expectation, and a table drawn showing the results. The formula $\delta = \sqrt{npq}$ was applied¹⁷ where n equalled the number of accents involved,¹⁸ p the chance dispersal total divided by n , and q equalled n minus the chance dispersal total divided by n . The formula applies equally well for units, continuous, or broken groups, when the chance expectation is known. It was applied first to units, then continuous groups, and finally disconnected groups with central tendencies.

In the examination of the 5953 instances of energy distribution in relationship to the pulse curve, it became clear that some portions of the curve are favorable to the development of large energy quanta, some are unfavorable, and other portions seemed indifferent. The latter may be the result of too few cases. All of the phenomena are of interest since all may lead to knowledge of a fundamental nature concerning the physiological determinants of intensive action.

It will save confusion to discuss first those areas of the pulse curve favorable to the distribution of accent. The onset of the primary wave of the radial pulse is the point where the largest total of accents occurred. It was at first assumed to be a result of the multiplication table, but the formula showed a t of 7.32.

¹⁷ The formula gives the value of the probable distribution by chance of the same type of items during a certain operation. 3 sigma (t equals 3.00) is assumed to be outside the probability of chance. While 2.50 is generally assumed to be certain, only 3.00 was accepted as final here. See Burgess, Robert W., *Introduction to the Mathematics of Statistics*, Houghton, Mifflin, 1927.

¹⁸ n is not the same on each percentage point, owing to the multiplication table, and this had to be calculated.

The members of the group 31–35% of the pulse curve inclusive were nearly all favorable, but were below the limits of certainty. When the two most favorable points in this group are examined together t equals 2.92, which is so close to certainty that they were held for special examination when the data was examined for types of speech and speakers.

The next group, 51–65% inclusive has a t of 4.11. Only one of the members, 64%, was large enough to have occurred outside of chance. Thus a process of elimination was carried out, testing all the possible combinations of members in this group. The final significant group was 51,54,55% with a t of 3.50. It was assumed that the favorability to accent develops rather suddenly here, and centers in this group. A second grouping was also discovered of 60–64% inclusive which was significant with a t of 3.08.

Considering next those portions of the radial pulse curve where significantly fewer accents fell, the first group encountered is 2–6% inclusive. The group has a t of only 2.78. When the point 5% is eliminated a t of 3.08 is achieved, and it may be accepted that the points 2,3,4,6% are unfavorable to the development of accent.

The group 39–49% inclusive has a t of 2.87 but was discarded for lack of confirmation in the more detailed examination later.

The final portion of the pulse curve (66–98% inclusive) develops some problems, because the second largest deviation from sigma (97%) occurs here, and overbalances all of this group. The group 95–98% inclusive has a t of 6.13. When 97 and 98% are removed from the group, the results are no longer significant. However a fall in significance occurs between 88–90% inclusive, and it was suspected that there might be a group between 66–87% inclusive. This group has a t of 1.46. However, when the members of the group which are not in accord with the central tendency are eliminated, the group is significant. These members that were dropped had no statistical significance in any combination, and must have fallen by chance caused by too few cases. The group centers in 72, 83, 86%.

ANALYSIS OF THE DATA INVOLVING DIFFERENT TYPES OF SPEECH AND SPEAKERS

The instances of accent studied were distributed in the following manner: Normals—Reading Aloud—3368 cases; Conversing with Operator—324 cases; Nonsense syllable “pa”—1042 cases; Nonsense

syllable series—241 cases; Sutterers—Reading Aloud: 631 cases; Conversing—150 cases. Total: 5756 cases.¹⁹

The procedure was the same as for the general analysis, followed by the application of the Bernoulli formula for units, continuous, and disconnected groups.²⁰ Due to the limitations of space it will not be possible to describe this process in detail. Confirmation was found in each type of speech of the groups and units already discussed. The stutterers, however, varied from the normal, and the results should be discussed.

a. Stutterers Reading Aloud

The group 13–19% is favorable to accent with a *t* of 2.50. Elimination raises the certainty to only 2.87. However, this result is partially confirmed in the Conversing group, and further experimentation might develop a statistically reliable group.

The group 44–72% inclusive is favorable to accent with a *t* of 3.94.

The group 20–43% inclusive is unfavorable to the production of large energy quanta with a *t* of 2.71. Elimination shows a group of 20,22,23,24,25,26,27,29,30,32,34,35,37,39,40,41,43% with a *t* of 3.64.

The group 72–79% can only be raised to a *t* of 2.71. However it is interesting to note that this group parallels the normal distribution, and might conceivably become significant with further study.

b. Stutterers Conversing With the Operator

The group 2–19% inclusive is favorable to accent when elimination has been carried out. The eliminated units are not significant.

It must be remembered that further study might develop other significant groups than the ones mentioned in this study. Thus a complete curve may not have been reached. The results attained, however, justify certain conclusions.

THE PORTIONS OF THE HEART BEAT AFFECTING THE DISTRIBUTION OF ENERGY

There was, in general, close agreement between the findings for the total experiment, and the various types of speech with normal

¹⁹ Two records of normal subjects reading aloud were inadvertently omitted from the analysis. 197 cases were involved.

²⁰ This rather arduous method of arriving at a common ground seemed to have no substitute, since examining each pulse beat and its accentual accompaniment on physiological grounds would not only have been inaccurate and illogical, but even more awkward.

speakers, the subjects saying "pa" forming two small extra groups favorable to accent 39-49% inclusive, and 88-90% inclusive, the explanation for which must be left to further investigation. This could have occurred as the result of cardiac changes in these subjects, or perhaps, the repetition of the monosyllables lies closer to the primitive speech pattern, and thus is more sensitive to changes in the heart beat. It will be seen that both of these groups follow closely upon significant changes in the cardiac cycle. In opening a new field of investigation many questions arise which cannot be answered with the data at hand. In one or two instances groups and units appearing in the total distribution did not occur in the partial distribution. The Bernoulli formula was applied, and showed that the absence of cases was responsible rather than any change in the phenomena.

The normal material will be examined first.

The portions of the radial pulse curve favorable to the development of large energy quanta are: 00%; 31,33%; 51-65% inc. The portions unfavorable are: 2,3,4,6%; 66-81% inclusive; 95-98% inclusive.

It is next necessary to see what the radial pulse represents in relation to the heart.

"The pulse in the arteries may be defined as a wave of pressure which is transmitted through the elastic vessels, and produces in their successive portions an expansion, an elongation, or both."²¹ Mechanico-pneumatic systems of recording these pressure changes utilize this expansion wave in order to achieve a relative measure of what is happening in the heart. In ventricular systole, a volume of blood is forced into the aorta, which becomes distended. This sudden distention sends an expansion wave down the arteries which gradually grows smaller, meanwhile altering some of its characteristics until it reaches the capillaries, where no sign of the pulse is left. When ventricular systole closes, the semilunar valves occlude and there is a sudden diminution of pressure in the aorta, followed by a slight increase. Thus the radial pulse consists of a primary or systolic wave, followed by a dicrotic notch, which represents roughly the close of systole.

Lewis²² remarks that the interval between the arterial upstroke

²¹ Wiggers, Carl J., *The Pressure Pulses in the Cardiovascular System*. Longmans, Green and Co., 1928, p. 67.

²² Lewis, Thomas (Sir), *The Mechanism and Graphic Representation of the Heart Beat*. 3d Edition. Paul B. Hoeber, 1925, p. 23.

and the dicrotic notch is a very inexact measurement of systole in the arteries, and of course, in the heart. He continues, however, by saying that the interval between one upstroke and another (the primary wave) is almost, if not quite as exact as curves taken with far more delicate apparatus. Thus the radial pulse gives a quite exact measurement of the duration of the cardiac cycle, although it is indirect and bears no relationship to blood flow, volume, or velocity.

In drawing inferences concerning the cardiac cycle from the radial pulse it is necessary to bear in mind the fact that the expansion wave occupies time in traveling from the aorta to the radial artery. Lamson²³ estimates this time at .10 second. Lewis²⁴ is perhaps more accurate in estimating it at .13 second, since he includes the .03 second delay caused by recording the carotid artery. If Lewis is correct, the point 00% does not occur on left ventricular systole but .13 second later. Wiggers²⁵ says that the velocity of the pulse is increased when the blood pressure is high or the arterial walls are tense. All subjects were assumed to be normal, but as will be seen later, this possibility may have entered the results.

The mean pulse time of the total experiment was 3.52 fifths of a second. Since most physiologies give cardiac measurements in decimals this is a rate of .704 second, or 85.23 beats per minute.²⁶

Each percentage point of the data, then, represents an elapsed time of .00704 second. Consequently left ventricular systole would commence approximately half-way between 81 and 82% of the data. Since a significant group closes here, the discussion of the cardiac cycle will be commenced from this point, although since the advent of electro-cardiography, auricular systole is conventionally chosen to initiate the cardiac cycle, due to the fact that the P or auricular wave initiates the action currents of the cycle.

The various general physiologies give only vague information on the duration of ventricular systole. At 72 beats per minute Halliburton and McDowall assume ventricular systole to continue about .30 second. At a rate of 63 per minute Lewis assumes it to continue about .38 second. At 70 per minute Howell assumes it to be .379 second. He quotes an experiment by Einthoven on a normal man

²³ Lamson, Paul Dudley, *The Heart Rhythms*, Baltimore: Williams and Wilkins Co., 1921, p. 21.

²⁴ *Ibid.*, p. 24.

²⁵ Wiggers, Carl J., *ibid.*, p. 75.

²⁶ This rather rapid rate is at least partially explained by the fact that the subjects were speaking during the experiment.

whose ventricular systole varied between .312 and .346 second in a series of fifteen heart beats.²⁷ The rate of the beat in this experiment is not given.²⁸ Wiggers²⁹ is the only physiologist to present data of a more or less exact nature on the duration of ventricular systole at varying rates of the heart.

The theoretical average of ventricular systole at rate 85 per minute is .25 second according to Wiggers.²⁹ At a rate of 85.23 this would give a duration of .248 second. A portion of ventricular systole is devoted to the isometric contraction phase.³⁰ Thus the measurement of 81.5% as the commencement of ventricular systole is actually that of effective ventricular systole, referred to by Wiggers as the ejection phase. The isometric contraction phase is that time in ventricular systole when the bicuspid and semilunar valves are closed, and is characterized by a steady rise in pressure until the semilunar valves are forced open by the increase in pressure.³¹ The time for this event has been estimated by Willius at .07 to .09 second, by Wiggers³² at .05 second at a rate of 75 per minute. At 85.23, this time would be .0459 second,³³ leaving the phase of effective ejection at .2021 second. This brings the end of ventricular systole to the point of the pulse 10.2%.

This period of ejection from the left ventricle may be divided into two phases, the period of maximum ejection, and the period of reduced ejection.³⁴ At 85.23 beats per minute, the time of maximum ejection would be .0827 seconds. This would concern the percentage points 81.5–93.25% of the radial pulse curve: The time of reduced

²⁷ Halliburton and McDowall, *A Handbook of Physiology*, 34th ed., P. Blakiston's Sons and Co., 1935, p. 127; Lewis, Sir Thomas, *The Mechanism, etc.*, . . . ; Howell, Wm. H., *A Text Book of Physiology*, W. B. Saunders and Co., 1934, 12th ed., p. 579.

²⁸ The reasons for this paucity of information are that ventricular systole can vary within limits without being pathological, and the generally assumed hypothesis that the principle change in the cardiac cycle at varying rates is in diastole.

²⁹ Wiggers, Carl J., *Physiology in Health and Disease*, Philadelphia: Lea and Febiger Co., 1934, p. 587.

³⁰ Wiggers, Carl J., *Pressure Pulses, etc.*

³¹ Willius, Fredrick, *Clinical Electrocardiography*, W. B. Saunders, 1932, p. 21.

³² Wiggers, Carl J., *ibid.*

³³ Assuming that the isometric phase reduces proportionately with ventricular systole, and that Wiggers is correct.

³⁴ Wiggers will be followed for the remainder of the discussion.

ejection would be .1194 second, or from the percentage points 93.25–10.25%. (That is, considering the point 00% as intermediary and going on through the cycle.)

The events of ventricular diastole are divided functionally into the phases of proto-diastole, isometric relaxation, rapid inflow, diastasis, and auricular systole. The proto-diastolic phase is devoted to bringing into apposition the semilunar valves which have already floated toward closure. At a rate of 85.23 per minute this phase occupies .0338 second, estimating that auricular systole is smaller in the same proportion as ventricular systole. The proto-diastolic phase would occupy the percentage points 10.2–15.0% inclusive.

In the isometric relaxation phase, the heart is relatively quiescent. At 85.23 per minute, it would occupy .0676 second. This would include the percentage points 15.0–24.61%.

There follows the period of rapid inflow, or as Lewis calls it, active diastole. At 85.23 per minute the percentage points included would be 24.61–37.82% inclusive.

Diastasis, or the passive phase of the heart occupies .1006 second, and the percentage points 37.82–60.63% inclusive.

Auricular systole occupies .101 second, and the percentage points 60.63–74.97% inclusive.

The isometric contraction phase occupies .0459 second and includes the percentage points 74.97–81.5 inclusive.

When the phenomena of the experiment are compared with the events of the cardiac cycle, it is interesting to note that there is an observable lag in the appearance of energy distributions of about .03 second. Each group is shifted to the right, (*i.e.*, farther along in the cardiac cycle) approximately .03 second, and if this shift had not occurred, all of the significant groupings would have tallied closely with significant changes in the functioning of the cardiac cycle.

There are several possible explanations, but with the data at hand it is impossible to come to a conclusion:

1. There may have been a constant error in the marking of radial systole in the records. The scratch, in the effort to mark the absolute onset of the upstroke, may have been set a fraction of a millimeter to the left.³⁵

³⁵ One mm. in these records represented about .101 second. The estimates should be correct to between .01 and .02 second, for any given measurement, and for a large series the mean of the error should be within the third decimal. (Verified by experiment.)

2. There may have been an error in assuming the arterial delay to be .13 second. That there is a range of error here is demonstrated by Wiggers.³⁶ "My own observations confirm the conclusion that the pulse velocities encountered in patients with hypertension certainly fall within the ranges found yearly in young, healthy medical students." According to Wiggers, the pulse velocities reported by various investigators range at age 26 from 4.8 to 8.4 metres per second. The variation is explained by the fact that the exact distance traversed from the aorta to the radial artery in any given individual can only be estimated.

3. There might possibly be a physiological lag from the occurrence in the cardiac cycle to the muscular structures involved in the production of large energy quanta. If Wiggers is correct in his statement that the speed of nervous propagation along these paths is 30-90 metres per second,³⁷ and if it is assumed that a metre is the distance traveled from the heart to the brain to the speech musculature, this would occasion a delay of about .03 second, estimating at the slowest speed of propagation of nervous impulse.³⁸

Which of these assumptions may be the closest to the truth is a matter of hazard. A combination of these and other factors may be involved. Regardless of what may later prove to be the truth, it must be accepted that the events of the cardiac cycle, as described, play important roles in the determination of energy distributions in speech. All such favorable and unfavorable points must be regarded as having occurred through the determining factors of the cardiac cycle, and *it may be stated as a law that the events of the cardiac cycle are physiological determinants of energy distributions in speech.*

The stutterers, however, show variations from the normal picture. The pulse rate is essentially the same³⁹ (3.519 normals, 3.524 stutterers), and since this has already been analyzed for its relationship to the cardiac cycle, it will be sufficient to note the phases of the cycle at which the energy distributions were affected.

The theoretical lag for stutterers seems to be .04 second instead

³⁶ Wiggers, Carl J., "Physical and Physiological Aspects of Hypertension, *Ann. Int. Med.*, Vol. 6, 1932, p. 14.

³⁷ Wiggers, Carl J., *Physiology in Health and Disease*, p. 63.

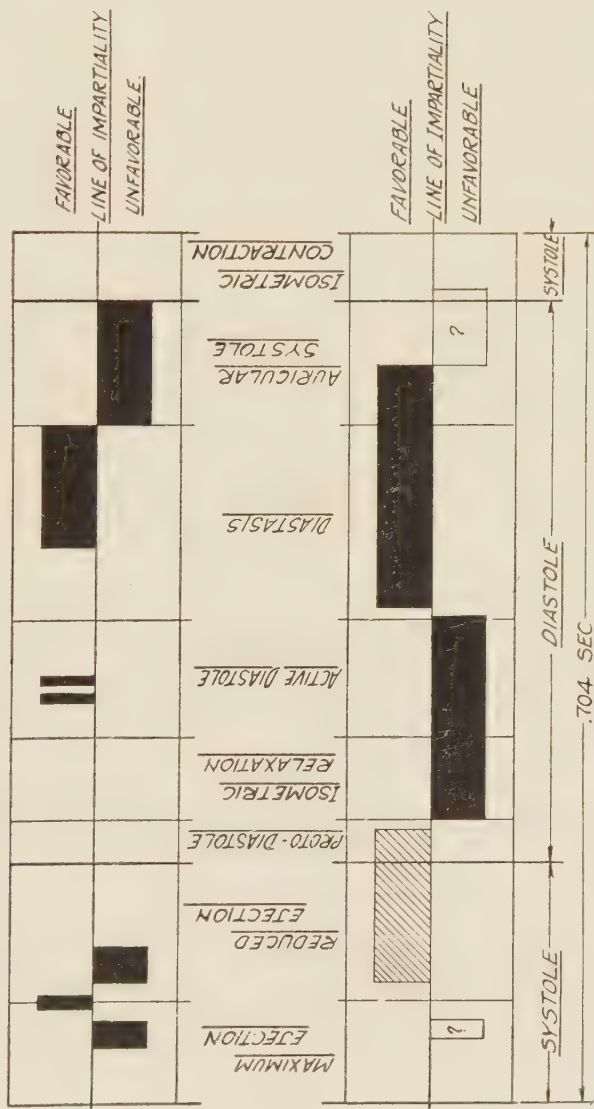
³⁸ The roughness of this calculation is realized.

³⁹ In contradiction of the results reported by Travis, Tuttle, and Cowan, "A Study of the Heart Rate During Stuttering," *Journal of Speech Disorders*, March, 1936. Travis, et al, reported that stutterers when speaking had a more rapid pulse rate than normals when speaking. Further study is indicated.

of .03 second, since the groups are displaced .01 second to the right even after the .03 second calibration. The first group encountered is the one presented by the stutterers conversing, favorable to accent, from 2-19% inclusive. Although mathematically uncertain, this group is confirmed by a similar group of stutterers reading aloud (more

SHOWING THE CARDIAC CYCLE'S INFLUENCE ON THE DELIVERANCE OF LARGE ENERGY

QUANTA BY NORMAL SPEAKERS



SHOWING HOW THE SMALL GROUP OF STUTTERERS DISTRIBUTED THEIR LARGE ENERGY

QUANTA IN ACCORDANCE WITH THE CARDIAC CYCLE

cases) of 13–19% inclusive. If .04 second is allowed as the lag, the group will occupy the reduced ejection phase of ventricular systole, and extend about .01 second into proto-diastole.⁴⁰

Immediately following this group is an unfavorable group 20–43% inclusive. It begins shortly before the close of photo-diastole, and ends almost at the close of active diastole.

The favorable group 44–72% inclusive commences at the beginning of diastasis, and continues into auricular systole about .04 second. This would seem to coincide with the phase of auricular systole described by Wiggers, which is a rise of ventricular and auricular pressure following auricular contraction. The beginning approximately of the rise in pressure marks the end of the favorable group.

The next group, 72–90% inclusive, is not mathematically certain but parallels the normal grouping. It commences at the beginning of the rise in pressure of auricular systole, and continues until its close.

For the same reason, 97 and 98% can be mentioned, although not mathematically certain. They are also unfavorable.

This picture of energy distribution by stutterers in relationship to the heart should be accepted only as tentative pending further investigation. It may be assumed, however, that the cardiac cycle does determine their energy quanta distribution, but in a differing way.

CONCLUSIONS

The data show a lag of approximately .03 second, and allowing this, the following portions of the cardiac cycle determine the corresponding events in the distribution of large energy quanta in speech:

a. At the close of the maximum ejection phase of ventricular systole, when the pressure in the ventricles and the volume of blood ejected is reaching its maximum, is a period of the cycle which is unfavorable to the development of accent. This is followed immediately by:

b. The favorable point 00% located at or near the point of greatest ejection, and is followed immediately by:

c. A short group of about .03 second which is again unfavorable to the development of large energy quanta, and which occurs as the pressure and volume flow from the ventricle begin to decline.

⁴⁰ The diagrams accompanying these notes present the data for the stutterers with the .03 lag, which has been calibrated. The need for another calibration of .01 second is evident.

d. Slightly towards the first portion of active diastole are two favorable points: 31,33% (about .034 second after the inception of the phase).⁴¹

e. The last portion of the period of diastasis is favorable to accent, and the beginning of auricular systole closes this favorable group.

f. Auricular systole is unfavorable to accent. .01 second after the isometric contraction phase of the ventricles commences this cycle is again impartial.

g. Stutterers when speaking do not follow the tendencies of normal speakers, except very roughly. Nevertheless the cardiac cycle determines the distribution of energy in a definite significant pattern. Much further study is indicated here, since clinical findings of importance may result. The present results seem to indicate stuttering as a phenomenon of neuro-physiological order rather than a so-called volitional or emotional disturbance.⁴²

APPENDIX

A number of additional investigations are immediately suggested:

1. The mechanism of the distribution should be studied.
2. Stutterers should be studied further.
3. It is only after about five minutes of speaking that these groups become mathematically significant. This should be studied.
4. No objective study after Muyskens has been made of meaning and energy distributions.
5. More exact quantitative measurements should be obtained with the cathode ray apparatus suggested here.
6. The relationship of the heart rate to the rhythmic recurrence of these accents should be studied. In the present records there was a slight positive correlation between the heart rate and the number of accents per minute.
7. During the measurement of the records, it was noticed that

⁴¹ The literature contains no explanation of this phenomenon. Howell quotes an early experiment by Einthoven, which shows an increase in electrical current from the afferent vagus fibers near or at this point in the heart beat.

⁴² In the diagrams the hatched areas represent the groupings confirmed by stutterers conversing. The questionable groups are indicated by open blocks. The grouping in both diagrams is superimposed upon a scaled time scheme of the cardiac cycle at this rate of the heart. The line of impartiality represents the chance distribution, the blocks above the groups favorable to accent, the blocks below those unfavorable. No comparative grouping is intended; simply the endurance time is represented.

there was a regular recurrence of large accents and smaller ones, a "family" so to speak. Is this the result of the Traube-Hering reflex, or does it come from some other unmeasured relationship with the vegetative functions? If other large movements such as those of the alimentary canal and the peristaltic tube were to be studied, perhaps a relationship would show. Certainly the knowledge of certain variant types of speech defects would lead one to this suspicion. There should be other determinants and regulators of the speech process. And other parts of the speech process closer or farther from primitivity should be studied in relationship to these determinants. The problem is of serious importance, due to its relationship to physiology and to pathological studies in speech.

